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Deformations of Space Photos

Imagery obtained from the various systems of the Ranger, Surveyor, Lunar Orbiter, Gemini and Apollo satellites have been processed to the extent of their geometric fidelity.

INTRODUCTION

SIR EDMUND HILLARY, one of the first two men to climb Mt. Everest, when asked as to what psychological imperative was behind that climbing, said "because it was there". The same spirit of exploration and desire of pioneering efforts has been with man through the centuries. The exploration methods and their scopes have been changing and, hopefully, improving continuously.

ABSTRACT: *The sources of image deformation include, in addition to the well-known aberrations of the camera lens, the unflatness of films, graininess of emulsions, and dimensional changes due to temperature and humidity variations. If a camera is moving, image motion occurs. Panoramic cameras produce photographs which are not central perspectives. Return-beam vidicon and multispectral scanner systems add kinds of deformations which differ in character from those encountered in conventional cameras. Reseaus are useful for the detection and correction of deformations. Data from non-frame photographs can be processed digitally with computers.*

Before the first man landed on the Moon we obtained through photogrammetry enough information about conditions there to assure the safety of our astronauts. We have adequately learned the details of the Moon's topography and have studied and analyzed its surface composition. Mars, Venus and other space bodies have also created considerable interest in us.

The first phase in such (space) explorations had to be earth-based, with observations, photography and measurements made by means of telescopes.

The second phase has been with man and scientific instruments lifted high in (or above) the earth's atmosphere, orbiting around the earth and to the moon. These experiments have proved that both man and his equipment are capable of working wonders. We have noticed that photography with visible light and highly developed camera systems will provide the highest information content and the most accurate measurements possible.

As we proceed with the next phases of exploring Mars, Venus and possibly the satellites of other stars, we become more and more aware of the problems of fundamental nature involving such photographic or other sensing systems. The value of imaging is currently well recognized by NASA and its Office of Advanced Research and Technology. However, until 1969–70, there has been very little direct research in this general area.

Man has been taking giant strides in space explorations through photogrammetry. Considerable progress has been made, yet we find ourselves somewhat frustrated. In order to reach the goal of perfection man has been introducing complications also. The closer we come to the state of zero error, knowingly or unknowingly we increase the error factors. We realize or discover that more error factors must be taken into consideration. This means that the task becomes more complicated. Thus, I must say, whereas perfection is approached, progress is getting more and more difficult.

In our quest for the improved metric capability of the space related photography, *Image Deformation* has to be understood, and the

* Presented at the International Symposium on Image Deformation, Ottawa, Canada, June 1971.

TABLE I. SOURCES OF IMAGE DEFORMATION

	Estimated Mean (Max) Residual Errors in µm (at the Negative)
I. *Camera Stationary*	
1. Due to Lens	
A. Radial & Tangential Distortions	3(10)
B. Chromatic Aberration	3(40)
2. Due to Camera	
A. Location to Principal Point	2(5)
B. Difference in Focal Length	—
C. Assumed Optical Axis	2(5)
3. Due to Film/Glass	
A. Imperfect Flatness	5(25)
B. Special Treatment (Baker-Nunn)	10(40)
C. Local Expansion or Contraction	3(15)
D. Local Emulsion Shift	—
E. Grains of Emulsion	2(5)
F. Temperature	2(5)
G. Humidity	(2)
4. Due to the Medium	
A. Atmospheric Refraction	1[e]
B. Atmospheric Turbulence	—
II. *Camera Moving*	
1. Shape of Object	—
2. Image Motions	
A. Space craft motion	
B. Space craft vibration	2(9)
3. Atmospheric Turbulence	—
III. *Non-conventional Photography*	
1. Panoramic Photography	10(50)
IV. *Complex Sensing System*	
1. Electronic Transmission Anomalies	—
2. Non-photographic Sensor: e.g., RBV Precision processing ~65 µm (1σ level, equivalent to 65 m in output image scale of 1:1 M). MSS Precision Processing: ~75 µm ($1\ \sigma$ level).	

means of eliminating it or overcoming the problem will have to be developed. In this respect the earth-based space photographs are the simplest ones (although the weakest ones for the space explorations). Here the sensing system stays stationary and the deformation of the image depends on the component parts, which can be checked and calibrated adequately.

The image deformation problem is complicated because the camera station moves where image smear due to vibration, relative (to object) translatory and rotary movements of the camera, atmospheric turbulence, etc., come into play. This problem is further complicated where some (other) devices are placed into the system in order to compensate for the above mentioned errors (e.g., Image Motion Compensation device). The system gets more complicated when the photography is special (e.g., strip or panoramic) or non-retrievable, or obtained through special systems (e.g., TV monitoring).

SOURCES OF DEFORMATION

It may be pertinent to consider the various sources of errors of image deformation and form a consolidated opinion on them in terms of progressively complicated systems of photography. (See Table 1).

CAMERA IS STATIONARY

Camera objective (*lens*). The known primary distortions may be considered in terms of radial and tangential components (e.g., in analogical solutions) or in terms of X and Y components (for computational solutions). These are primarily due to a combination of thick lenses, aperture of lenses, errors in installations of lenses, spherical aberrations, coma, astigmatic aberration and warping of the image plane, etc.

Because of chromatic aberration, the image-location may differ according to the color of the ray.

Deformations inherent to the camera body. The location of Principal Point is basically a conceptual error, depending on the assumed definition and proper handling of the conception. There are various definitions of the principal point: fiducial center, plate perpendicular from the interior nodal point, point of auto-collimation, etc. Even if a proper definition under the working procedure is assumed and considered, some residual errors always remain affecting the metric capability of the photograph.

The Calibrated Focal Length is always somewhat different from the physical focal distance. This has no practical effect in the photographs of objects placed at infinity. However, this may affect the metric capability if one tries to match or correlate photographs taken from close range to those taken from long range with the same camera.

Due to the Assumed Optical Axis, corresponding to a tilt in the interior geometry of the camera (which may correspond to locally changed focal length in the computational approaches), the discrepancy is similar to the asymmetrical distortion of the lens, accountable by the thin-prism conception (or the decentering distortion).

Deformations in the original film/glass negative. Due to imperfect flatness of the negative, the effect is that of a local change of the focal length and the associated unsharpness of image plus the associated distortion of the image point.

Due to special treatment of film, e.g., in the Baker-Nunn Camera (for Earth-based tracking of Earth Satellite), where the film is stretched to conform to the aspherical shape of the focal surface prior to exposure[1], in normal cameras one can expect all kinds of stresses and strains involving the film. This will, however, be almost nil with glass plates.

Local emulsion or contraction of film base is always unpredictable. Local emulsion shift can be unpredictable and in any direction.

An image is formed by an assemblage of fine grains in the emulsion. No image can be formed of the object smaller than the individual grain. The grains in emulsions of high sensitivity can be of average dimaeter of the order of 5 μm although generally they are between 1 μm and 3 μm in diameter. In practice, a grain of the emulsion exposed to light spreads its excitation to the neighboring grains and creates problems for the working photogrammetrist.

Dimensional changes due to temperature can be under sufficient control in earth based photography but, in high-flown or space photography, the variation in the temperature may be of significant concern. This is, however, lessened with the use of a port cover glass, which on the other hand may create a additional problem of refraction.

Dimensional changes due to humidity, even during the processing of the film, can be very significant at times[4].

Deformation due to the Medium. Atmospheric refraction depends on the incident angle, temperature, pressure and humidity conditions along the ray path, plus the air current.

CAMERA IS MOVING AND IS AIR BORNE (or is in a space vehicle).

Further complications are brought into the system if the camera is air (or space) borne and, as such, the following other deformation sources must be added to those listed above.

The shape of the space object (e.g., sphericity of the earth, moon or similar object) can be overcome or avoided with adequate control, the use of stereo-photography and rectangular spatial coordinates.

Image Motion of Various Types has been known to be the primary cause of all significant degradations of the space (air) photography[6]. (Also it is the most frequent and at the same time the most damaging form of deficiency likely to appear in images relating to the space explorations).

Spacecraft (aircraft) motion and the associated blur appearing due to the movement of the space craft during the opening of the shutter can be, to a great extent, compensated by using the IMC (Image Motion Compensation) Device. There are three main methods of accomplishing IMC:

By moving the platen-film assembly,
By moving the lens cone, and
By using the focal-plane shutter.

It may be mentioned here that often the third method is combined with the first or the second. Whereas the first or the second method tends to destroy the interior geometry of the camera system, the third one creates a situation somewhat similar to the strip camera, i.e., instead of giving a central perspective of a frame photograph, it represents an infinite number of line photographs with respect to a continuously changing perspective center (a locus of the projection center).

Devices such as Electro-mechanical *V/H*-Sensor cam correlator were used in the Lunar Orbiter systems[6] and were extremely successful in obtaining comparatively sharp images although their intrinsic metric quality are yet fully unassessed.

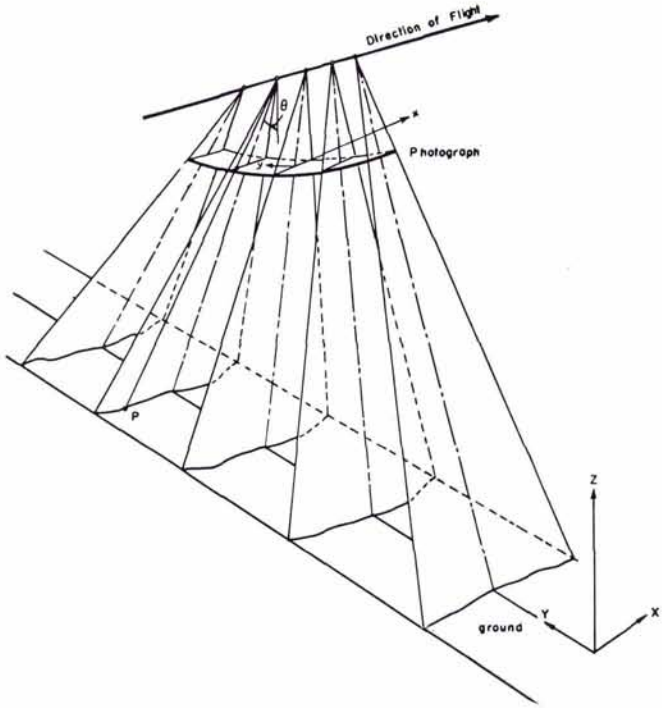

FIG. 1. Panoramic Photography.

Spacecraft (aircraft) vibration also causes blur of another kind. The vibration can be internal to the camera (because of the required use of various devices associated with the camera) or can be external (due to various mechanisms of the vehicle and the vehicle itself). Anti-vibration devices are being used now-a-days, but a fully vibration-free system is yet to be developed. Also a clear understanding of this problem through fundamental research is lacking.

Image blur due to atmospheric turbulence. Optical and photoelectric restoration of the images degraded by atmospheric turbulence have been attempted. The experiments have shown results that are improved in appearance, but their metric quality still remain doubtful. Motion degradation is one of the most important areas of concern in space photography.

In all these attempts, if the type of the error source is known from prior information, the quality of the image can be improved. But *postfacto* removal of the degradation is yet imperfect and as yet unworkable for precision work. Improvements have been attempted with somewhat successful results by both digital and non-digital processing techniques (See Reference 6 for details). However, in all these, considerable scope exists for further improvements.

NON-CONVENTIONAL (NON-FRAME) PHOTOGRAPHS

A typical example of a non-conventional photograph is the Optical Bar (610 mm) Panoramic Camera, (Figure 1) being used in the Apollo 15, 16 and 17 missions. Here, as compared to the frame cameras, the image deformations are systematic but complex. The photograph can no longer be considered as a central perspective. An inadequate understanding and data handling would leave some residual deformation in such imagery. The system is further complicated if the camera is operated in the stereo-mode (complexity due to insufficient knowledge of the atmosphere, terrain ruggedness, tilt angles, sweep rate, etc.). Here the limiting resolution may be considered as equivalent to the residual deformation (viz., 2 m on ground from 110 km circular orbit).

COMPLEX SENSING SYSTEM (not exactly photographic).

Typical examples of complex sensing systems are the Lunar Orbiter[7], the ERTS (Eart Resources Technology Satellite[2]) and the Mariner systems[3,8].

Blemishes due to electronic transmission anomalies, e.g., in the Lunar Orbiter Systems, whose understanding and then the reduction and elimination constitute a comparatively

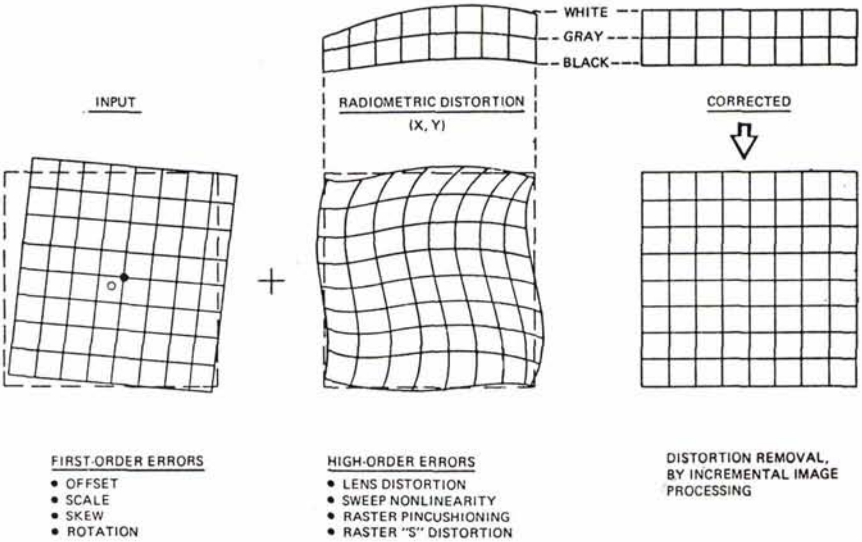

FIG. 2. Distortion correction for Return-Beam-Vidicon imagery*.

new problem in space photogrammetry. Some interesting studies in this respect may be found in Reference 9.

Deformation due to non-photographic sensors, e.g., the RBV (Return Beam Vidicon) camera, is essentially that of a frame-type camera except that the sensitive surface is the face plate of a vidicon tube rather than a photographic film.

When the Mariner camera, as an example, is shuttered, the Martian surface in view is imaged on the surface of the vidicon tube. An electron beam then scans the image and the image on one scan line is subdivided into (approximately) square picture elements called *pixels*. The intensity of the light in one pixel is averaged and encoded as a binary number for transmission to earth. A total of about 660,000 pixels (each encoded and transmitted as binary digits) are contained in one photograph. On receipt of telemetry data from the space craft, the binary data bits are reconstructed into hard-copy photographs. This system, apart from the distortion due to the lens, contains errors due to

Scan sweep non-linearity,
Raster pin-cushion distortion and
Raster *S*-curve distortion (Figure 2).

Because of our awareness and prior knowledge of such deformations, the face plate of the tube in the RBV camera will carry, in the future, a pattern of engraved crosses (reseau) whose locations will be determined prior to the installation of the cameras in the space craft. In the end, then, measurement of these crosses on the Bulk Processed images would help correct the errors.

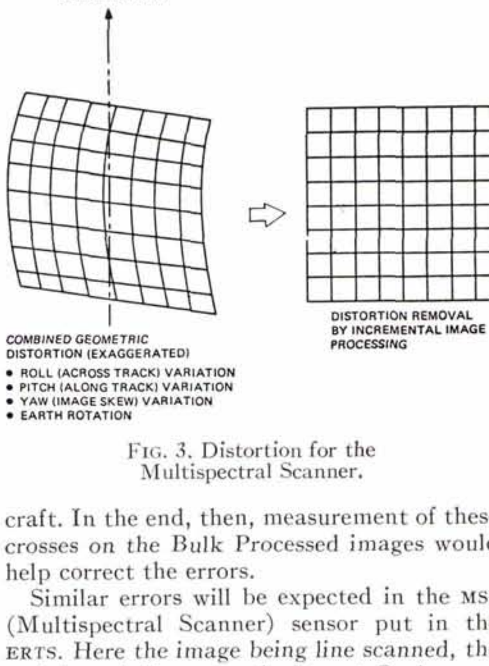

FIG. 3. Distortion for the Multispectral Scanner.

Similar errors will be expected in the MSS (Multispectral Scanner) sensor put in the ERTS. Here the image being line scanned, the scale is variable across the format. Such errors can be corrected by the knowledge of the sensor geometry, possibly with the use of a test or calibration range data. (See Figures 3 and 4).

CONCLUSIONS

The photographs taken by a variety of cameras and sensing systems during the Ranger, Surveyor, Lunar Orbiter, Gemini, Apollo programs have been used as much as possible within their limitations. Howsoever

* Figures 2, 3 and 4 are based on information obtained from NASA.

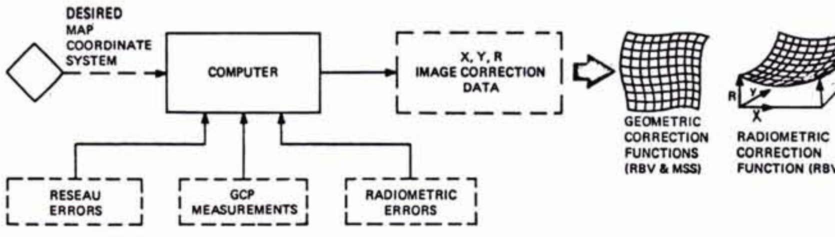

FIG. 4. Transform computation (RBV and MSS).

it may hurt our ego, it must be admitted that until now, in none of these applications have photogrammetric considerations been paramount in the design or operation of the system. As a result, the space-related data or maps that originated from these systems were possible due to the skill, patience, and hard labor of the photogrammetrists that were involved in the work. It was only in 1969 that a special team was appointed by the NASA to recommend the use of more suitable cameras and systems planned for the later missions and the Skylab.

Photographs with frame-type cameras are the ones for which complete analog processing systems have been developed. Photogrammetric plotting instruments can recreate the interior geometry of the camera, its position and altitude in space, and provide transformation from the image space to the object space in the appropriate reference system. On the other hand, data from non-frame photographs or other sensors have to be handled digitally or in a combination of analog-digital systems.

As the systems are becoming very complicated (involving many components), the analog procedures of elimination of deformations stay incomplete and insufficient. On the other hand the highly sophisticated and versatile digital computers are found uniquely useful in solving such problems. In such digital solutions, several approaches have been developed and tried (e.g., collinearity condition, coplanarity condition, etc.) in the field of photogrammetry.

The application of a particular approach must depend on the peculiarity of the system involved in in the process. Thus in many instances the coplanarity, scale restraint, etc., conditions may not even be applicable. In such applications the collinearity condition is of considerable help. Depending on the type of deformation on the image plane, inasmuch as the collinearity condition is a functional relationship (maintaining the condition that the image point, object point and the projection center are collinear it is easily applicable to any set of data which can be expressed in the form of a photograph, obtained directly or indirectly.

Reseaus of various types (usually in the form of tiny crosses) are being used in almost all photographic systems because of their proven values in checking deformations. Dynamic auxiliary data consisting of (binary coded) time and altitude, for example, are being used as when they are considered significant. A record of exposure time for each photo frame is also usually maintained.

Our recent experiences[5] at the Ohio State University indicate that satisfactory solutions to the problem are possible with a properly augmented collinearity condition based on a thorough knowledge of the involved dynamic system, and by using presently available extra-high speed versatile computers. This may be eventually costly, time consuming and, surely, frustrating. But that is the price we pay for *splitting hairs* or, currently, crossing the micrometer barrier.

BIBLIOGRAPHY

1. Brandenberger, A. J., "The Use of Baker-Nunn Cameras for Tracking of Artificial Earth Satellites," *Photogrammetric Engineering*, Nov. 1962.
2. Doyle, F. J., "Interpretation of Spatial Relationships," Paper presented at the International Workshop on Earth Resources Survey Systems. University of Michigan, Ann Arbor, Michigan, U.S.A., May 1971.
3. Glasstone, S., *The Book of Mars*, NASA Publication, Office of Technology Utilization, 1968.
4. Merchant, D. C.: "Calibration of the Aerial Photographic System," Ph.D. Dissertation, The Ohio State University, Columbus, Ohio, 1967.
5. Morgan, P. J., "An Investigation Into Some Problems Associated with Lunar Orbiter Photography," Ph.D. Dissertation, The Ohio State University, Columbus, Ohio, U.S.A., 1971.
6. NASA, "Evaluation of Motion-Degraded Images," Report on a NASA Seminar, Dec. 5–8, 1968. Publication No. NASA SP-193, 1969. (Library of Congress Catalog Card No. 75-600852).
7. Norman, P. E., "Out of This World Photogrammetry," *Photogrammetric Engineering*, vol. 35, No. 7, 1969.
8. Stephens, J. M., "A New Advance in Planetary Mapping," Paper presented at the annual ASP Convention in March 1971.
9. Wong, K. W., "Geometric Distortions in Television Imageries," *Photogrammetric Engineering*, vol. 35, No. 5, 1969.